AD 718567

3925

28 December 1967

Materiel Test Procedure 5-2-531
White Sands Missile Range

U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

GROUND GUIDANCE COMPUTERS

1. OBJECTIVE

The objectives of this Materiel Test Procedure (MTP) are:

a. To identify and evaluate the functional elements of ground guidance computers.
b. To provide general testing procedures for analog and digital computers.
c. To provide a method for evaluating the degree of automation of a computer.

2. BACKGROUND

Most missile guidance systems employ ground based computers for all or part of the guidance calculations required to accomplish the mission of the missile. The computer mechanization is either analog, digital, or a combination of both. The major elements of missile guidance computers which must be evaluated in any engineering test program include the input elements, storage elements, processing or computing elements, and the output elements. The requirements for precision, accuracy, and stability vary considerably from system to system. The evaluation techniques generally are determined by the accuracy and precision of the system under test.

3. REQUIRED EQUIPMENT

a. Potentiometers
b. Digital Voltmeters and Vacuum Tube Voltmeters
c. Phase Meters
d. Strip Chart and Direct Writing Recorders
e. Function Generators
f. System Programming Equipment
g. Digital Pulse Generators
h. Indicator Banks
i. Digital Counters
j. Digital Printers
k. Dual-beam Oscilloscope
l. Oscilloscope with Memory Device
m. Sweep Drive Unit
n. X-Y Plotter
o. Frequency Meters
p. Time Interval Counter
q. Trigering Device
r. Signal Generators
s. Wave Analyzer

t. Distortion Analyzer
u. Phase Shift Network
v. Power supplies, A-C and D-C
w. Switches, Decade Box, Potentiometers

4. REFERENCES

A. ORD 20-291, Ordnance Corps Phamplet, Surface to Air Missile Series, Part 1 Systems Integration.
B. ORD 20-292, Ordnance Corps Pamphlet, Surface to Air Missiles Series, Part II Weapons Control.
C. ORD 20-293, Ordnance Corps Pamphlet, Surface to Air Missile Series, Part III Computers.
D. Ridenour, L.N., (Editor-in-Chief), Radiation Laboratory Series Massachusetts Institute of Technology, Computing Mechanisms and Linkages, Volume 27, McGraw-Hill Book Company, New York, New York, 1948.
E. Nixon, F.E., Principles of Automatic Control, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1956
F. Phister, M., Jr., Logical Design of Digital Computers, John Wiley and Sons., Inc., New York, New York, 1958.
G. Skolnik, M. I., Introduction to Radar Systems, McGraw-Hill Book Company, New York, New York, 1962.
H. MTP 5-2-532, Computers (Electronic)

5. SCOPE

5.1 SUMMARY

This MTP describes the procedures required to determine the applicability of ground guidance computers to the intended usage. The procedures for conducting the tests are summarized as follows:

a. Analog Computers - The considerations and techniques for testing the major elements of an analog computer include:

1) Individual Circuit Tests - These tests provide for an analysis of the individual components of an analog computer system. The units that will be tested are computing amplifiers, limiters, timers, integrators, differentiators, control and magnetic amplifiers, comparators, and mixers.
2) Static Tests - These tests provide for analysis of the presence of bias and the standard deviation of the input and output analog voltages of the computer.
3) Dynamic Tests - These tests provide for an analysis of the dynamic accuracy of the computer including time lags, and the ability of the computer to perform coordinate conversion computation.

4) Dynamic Evaluation - This test provides for a determination of the bandpass characteristics of the servo loop, and for an analysis of the magnitude and direction of commands, time-of-flight, miss-distance computations, and proper sequencing of the switching functions of the analog computer.

b. Digital Computers - The considerations and techniques for testing the major elements of a digital computer include:

1) Input Unit Static and Dynamic Tests - These tests determine the static and dynamic accuracy and precision of the input and output encoders and digitizers, as well as the data rate of the encoder outputs. Computer parameters, such as logic organization, word length, and clock frequency are also determined.
2) Memory Unit Test - This test provides an analysis of the access time and the memory cycle,and the adequacy of storage of the computer memory units.
3) Arithmetic and Programming Unit Test - This test determines the adequacy of the units in terms of the real time involved. The computer logic organization is evaluated in the light of system requirements and specifications.
4) Computer Outputs and Displays Test - This test determines the computer's speed of operation, adequacy of information, and ability to interpret registers on demand.
5) System Dynamic Tests - These tests determine the adequacy of system performance by providing an analysis of the computer outputs for comparison with system specifications and requirements.

c. Degree of Automation - This procedure provides for an analysis of the degree of automation built into the guidance computer to be included in an overall evaluation of the computer.

5.2 LIMITATIONS

The procedures contained in this MTP intentionally are made general to provide computer tests that are applicable to a variety of ground guidance systems and test conditions.

6. PROCEDURES

6.1 PREPARATION FOR TEST

a. Select test equipment having an accuracy of at least 10 times greater than that of the function to be tested.

b. Record the following information:

1) Nomenclature, serial number(s), and manufacturer's name of test item(s)
2) Nomenclature, serial number, accuracy tolerances, calibration requirements, and last date calibrated of the

electronic test equipment selected for the tests

c. Ensure that all test personnel are familiar with the required technical and operational characteristics of the item under test, such as stipulated in Qualitative Materiel Requirements (QMR), Small Development Requirements (SDR), and Technical Characteristics (TC).

d. Review all instructional material issued with the test item by the manufacturer, contractor, or government, as well as reports of previous tests conducted on the same types of equipment, and familiarize all test personnel with the contents of such documents. These documents shall be kept readily available for reference.

e. Thoroughly inspect the test item for obvious physical and electrical defects such as cracked or broken parts, loose connections, bare or broken wires, loose assemblies, bent relay and switch springs, and corroded plugs and jacks. All defects shall be noted and corrected before proceeding with the test. Ensure that the test item conforms to the specified size and weight requirements.

f. Subject all circuits of the test item to a continuity test to determine that circuit impedances are as intended and that no damage will result when power is applied. Malfunctions shall be noted and corrected.

g. Prepare record forms for systematic entry of data, chronology of test, and analysis in final evaluation.

h. Assure that qualified safety personnel maintain a continuous observation of the test item through the entire test period to include unsafe conditions or practices related to the use of the test item.

i. Prepare a detailed flow diagram identifying the functional elements of the computer.

j. After power is applied, adjust the supplies for correct voltage and allow sufficient warmup time for stable operation.

6.2 TEST CONDUCT

6.2.1 Analog Computers

6.2.1.1 Individual Circuit Tests

6.2.1.1.1 Computing Amplifier Drift Test

a. Connect a power supply and a direct writing recorder to the amplifier under test as shown in Figure 1.

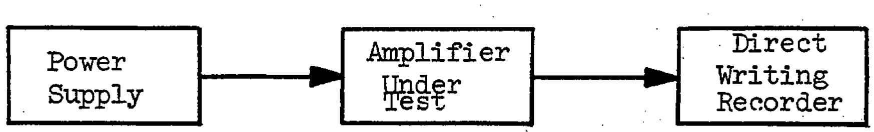

Figure 1. Typical Amplifier Drift Test Configuration

b. Apply equipment power and adjust the recorder for full scale deflection of the amplifier output signal.

c. Ground the input of the amplifier and adjust the recorder so that it is operating at low speed.

d. Continue to record until the amplifier output begins to drift or until the drift stability specification requirements have been exceeded.

6.2.1.1.2 Computing Amplifier Dynamic Range Test

a. Connect a function generator, a power supply, a direct writing recorder, and a dual beam oscilloscope to the amplifier under test as shown in Figure 2.

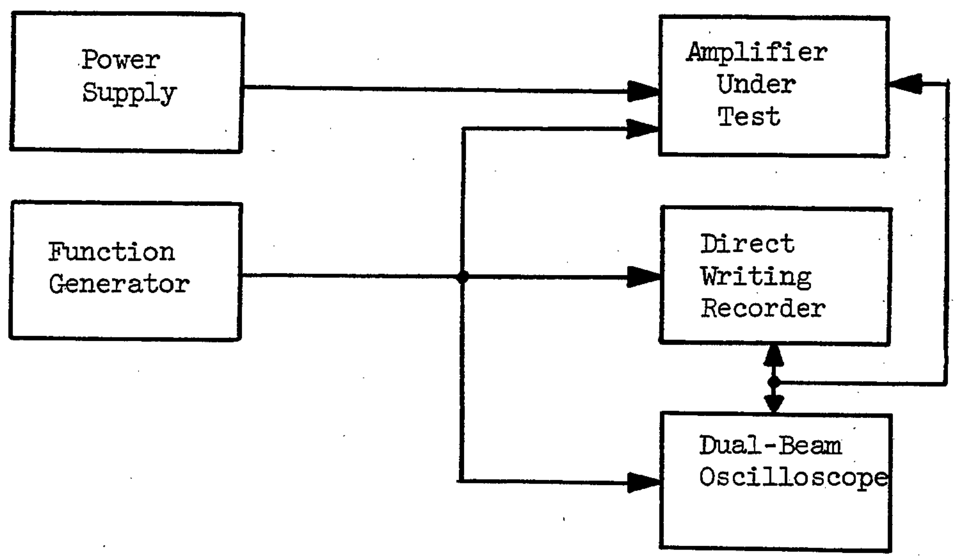

Figure 2. Typical Amplifier Dynamic Range Test Configuration

b. Determine the frequency and amplitude range of the amplifier under test from the manufacturer's specifications. Apply equipment power and adjust the function generator to produce a varying d-c output which is within the frequency range of the amplifier.

c. Adjust the recorder for a satisfactory display of the amplifier input and output signals.

d. Starting with the d-c level at zero, slowly increase the amplitude of the function generator (in a positive direction) until the maximum design input voltage level of the amplifier is reached.

e. Measure the input signal level with the oscilloscope and record this value as the maximum voltage level of the amplifier.

f. Repeat Steps (d) and (e) above, increasing the amplitude of the generator from zero to the maximum design negative voltage input level of the amplifier.

6.2.1.1.3 Limiter Tests

Determine the limiter slope, limiting voltage, limiting action, and repeatability accuracy of each limiter circuit as outlined in MTP 5-2-532.

6.2.1.1.4 Timer Tests

Determine the time interval control accuracy and reset capability of each time delay device as outlined in MTP 5-2-532.

6.2.1.1.5 Integrator Tests

Determine the circuit sensitivity, frequency response, linearity and response time, and stability characteristics of each integrator circuit as outlined in MTP 5-2-532.

6.2.1.1.6 Differentiator Tests

Determine the circuit sensitivity, frequency response, linearity and response time, and stability characteristics of each differentiator circuit as outlined in MTP 5-2-532.

6.2.1.1.7 Control and Magnetic Amplifier Tests

Determine the circuit sensitivity and gain, frequency response, stability, and harmonic distortion characteristics of each control and magnetic amplifier as outlined in MTP 5-2-532.

6.2.1.1.8 Comparator Tests

Determine the circuit sensitivity and linearity, output versus frequency, output versus phase, and stability and null characteristics of each comparator circuit as outlined in MTP 5-2-532.

6.2.1.1.9 Mixer Tests

Determine the circuit amplitude, harmonic distortion, intermodulation distortion, and phase characteristics of each mixer circuit as outlined in MTP 5-2-532.

6.2.1.1.10 Control Amplifier Tests

Determine the circuit sensitivity and gain, frequency response, stability, and harmonic distortion characteristics of each amplifier circuit as outlined in MTP 5-2-532, for control and magnetic amplifiers.

6.2.1.2 Static Tests

a. Connect the radar and an oscillograph to the computer under test as shown in Figure 3.

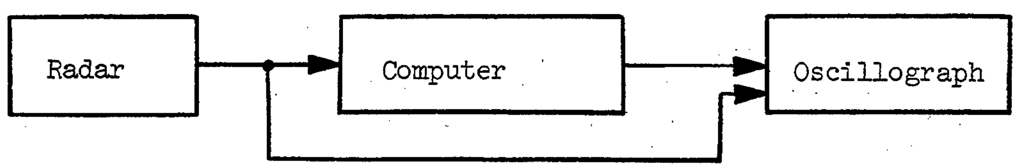

Figure 3. Typical Computer Static and Dynamic Test Configuration

b. Energize the radar and computer and calibrate the oscillograph in accordance with applicable procedures.

c. Set the radar range dial to minimum range, and the radar elevation and azimuth dials to zero mils.

d. Divide the minimum to maximum radar range into 64 equal increments and set the radar range dial to the value of the first increment. Set the azimuth and elevation of the radar to plus 100 mils as indicated by the radar dials.

e. Record the amplitude of the computer input and output analog voltages using the oscillograph.

f. Increase the radar azimuth and elevation settings 100 mils and set one additional increment of range into the radar range unit.

g. Repeat Step (e) above.

h. Repeat Steps (e) and (f) above, through the entire range of the radar in azimuth and elevation in increments of 100 mils, adding one increment of radar range for each 100 mil increment of azimuth and elevation.

6.2.1.3 Dynamic Tests

6.2.1.3.1 Dynamic Accuracy

a. Mount motion picture cameras with coded timing film in a suitable position on the radar to photograph the azimuth, elevation, and range dials.

b. Connect the radar and a time coded oscillograph to the computer under test as shown in Figure 3.

c. Energize the radar and computer, and calibrate the oscillograph in accordance with applicable procedures.

d. Divide the maximum azimuth, elevation, and range slewing rates of the radar into ten equal increments.

e. Insert the smallest incremental slewing rate into the radar azimuth, elevation, and range units, and start the time coded motion picture cameras and oscillograph simultaneously.

f. Record the computer input and output analog voltages while slewing from minimum to maximum in range and elevation, and through 6400 mils in azimuth.

g. Insert one additional increment of slewing rate into the radar azimuth, elevation, and range units and repeat step (f) above.

h. Repeat Step (g) above, eight additional times until the radar is slewing at its maximum rate in azimuth, elevation, and range.

6.2.1.3.2 Dynamic Evaluation

a. Connect a target position function generator, a missile position simulator, and a suitable test and evaluation recorder (e.g. oscillograph, strip chart, or integrated event recorder) to the computer under test as shown in Figure 4.

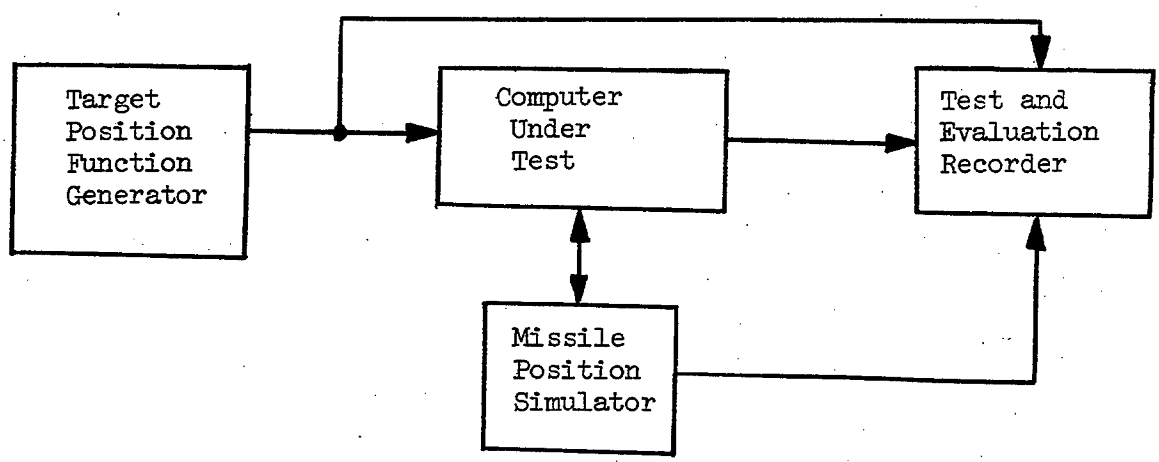

Figure 4. Typical Computer Dynamic Evaluation Test Configuration

b. Apply equipment power and calibrate the test evaluation recorder in accordance with applicable procedures.

c. Insert a simulated firing engagement problem into the computer utilizing the target and missile position generators.

NOTE: The firing problem to be inserted will depend upon the particular parameters to be investigated, e.g., coordinate conversion from missile axes to radar polar on Cartesian coordinates is best simplified by limiting the engagement to a particular course, such as an incoming course along one of the system coordinate axes.

d. Record the input variables to the computer and the output parameters utilizing the test and evaluation recorder.

e. Repeat Steps (c) and (d) above, for each computer problem to be investigated.

6.2.2 Digital Computers

NOTE: Prior to performing the digital computer tests listed below, check with an oscilloscope to ensure that amplitude, pulse width, and frequency of the computer master clock is within specifications.

6.2.2.1 Input Unit Tests

6.2.2.1.1 Static Tests

a. Depending upon the configuration of the computer under test, connect the radar and an indicator light bank or an oscilloscope with a memory device, to the input unit under test as shown in Figure 5.

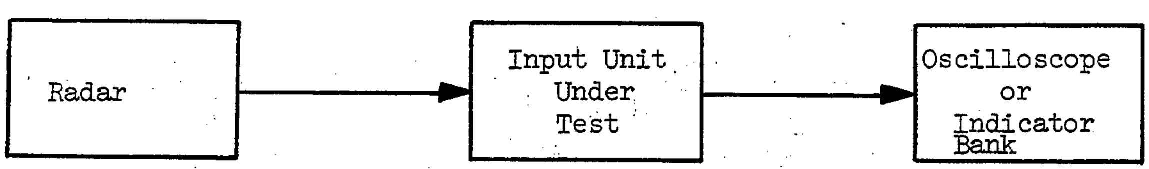

Figure 5. Typical Input Unit Test Configuration

b. Apply equipment power and, if necessary, calibrate the oscilloscope in accordance with applicable procedures.

c. Set the radar range dial to minimum range and the radar azimuth and elevation dials to zero mils.

d. Divide the minimum to maximum radar range into 64 equal increments and set the radar range to the value of the first increment. Set the azimuth and elevation of the radar to plus 100 mils as indicated by the radar dials.

e. Measure the state of each output register or display of the input unit and record on a suitable data form.

f. Increase the azimuth and elevation settings of the radar 100 mils and set one additional increment of range into the radar range unit.

g. Repeat Step (e) above.

h. Repeat Steps (e) and (f) above, through the entire range of the radar in azimuth and elevation in increments of 100 mils, adding one increment of radar range for each 100 mil increment of azimuth and elevation.

6.2.2.1.2 Dynamic Tests

a. Mount motion picture cameras, with coded timing film, in a suitable position on the radar to photograph the azimuth, elevation, and range dials.

b. Connect the radar, a digital processing unit, a real time clock, a reference generator, a word pulse generator, and magnetic tape deck to the input unit under test as shown in Figure 6.

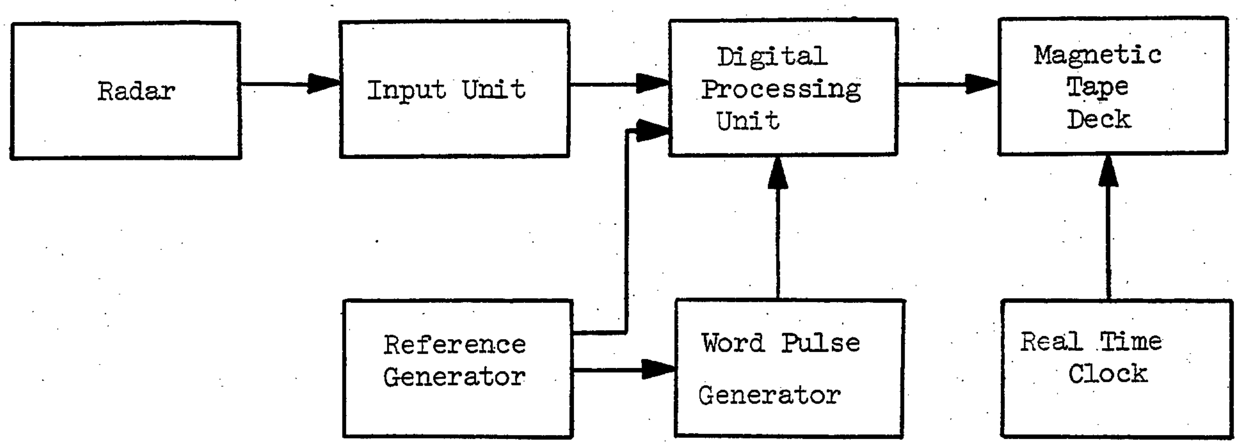

Figure 6. Typical Computer Dynamic Test Configuration

c. Divide the maximum azimuth, elevation, and range slewing rates of the radar into 10 equal increments.

d. Insert the smallest incremental slewing rate into the radar azimuth, elevation, and range units, and start the time coded motion picture cameras and magnetic tape deck simultaneously.

e. Record the input unit output on magnetic tape while slewing from minimum to maximum in range and elevation, and through 6400 mils in azimuth.

f. Insert one additional increment of slewing rate into the radar azimuth, elevation, and range units, and repeat Step (e) above.

g. Repeat Step (f) above, eight additional times until the radar is slewing at its maximum rate in azimuth, elevation, and range.

6.2.2.2 Memory Unit Test

Using a dual-beam oscilloscope, determine and record the access time and memory cycle time of the memory unit under test.

6.2.2.3 Arithmetic and Programming Units Test

If required, determine and record the condition of any module in the digital system of the arithmetic and programming units under test using a test word and dual-beam oscilloscope.

6.2.2.4 Computer Outputs and Displays Test

Determine and record the speed of operation, adequacy of readout information (such as the number of digits displayed) and the ability to interpret registers on demand for the computer under test.

6.2.2.5 Systems Dynamic Testing

a. Perform a routine program to exercise the computer and indicate units which are not operational, utilizing the self-test digital tapes or cards supplied with the computer.

b. Record any malfunctions and discrepancies on a suitable data form.

6.2.3 <u>Degree of Automation</u>

a. During conduct of all the preceding tests, determine if the operator's controls are adequate for the job to be done and if they are located in logical places with respect to the operator so as to reduce his reaction time and keep his fatigue to a minimum.

b. Determine if the computer displays are easily accessible to the operator and if they can be read accurately and conveniently by the operator as he operates the control which affects the display.

c. Determine if there is sufficient data, supplied at an adequate rate, for the operator to make decisions or perform a part of the computer operation.

d. Determine if lighting, heating, air conditioning, and operating space are adequate for proper operator performance and comfort.

e. Record all observations made during performance of Steps (a) thru (d) above.

6.3 TEST DATA

6.3.1 Preparation for Test

a. Record the following:

1) Nomenclature, serial number (s), and manufacturer's name of the test item (s).
2) Nomenclature, serial number, accuracy tolerances, calibration requirements, and last date calibrated of the test equipment selected for the test.
3) Discrepancies and deficiencies noted in equipment inspection prior to start of the test.
4) Malfunctions noted and corrective action taken during conduct of continuity checks performed prior to start of the test.

6.3.2 Test Conduct

Data to be recorded in addition to specific instructions listed below for each individual subtest shall include an engineering log book containing, in chronological order, pertinent remarks and observations which would aid in a subsequent analysis of the test data. This information may consist of temperatures, humidity, and other appropriate environmental data, or other description of equipment or components, and functions and dificiencies.

6.3.2.1 Analog Computers

6.3.2.1.1 Individual Circuit Tests

a. Computing Amplifier Drift Test - Record the output of the amplifier.

b. Computing Amplifier Dynamic Range Test - Record the maximum positive and negative voltage levels of the amplifier.

c. Limiter Tests - Record data in accordance with the procedures contained in MTP 5-2-532.

d. Timer Tests - Record data in accordance with the procedures contained in MTP 5-2-532.

e. Integrator Tests - Record data in accordance with the procedures contained in MTP 5-2-532.

f. Differentiator Tests - Record data in accordance with the procedures contained in MTP 5-2-532.

g. Control and Magnetic Amplifier Tests - Record data in accordance with the procedures contained in MTP 5-2-532.

h. Comparator Tests - Record data in accordance with the procedures contained in MTP 5-2-532.

i. Mixer Tests - Record data in accordance with the procedures contained in MTP 5-2-532.

j. Amplifier Tests - Record data in accordance with the procedures contained in MTP 5-2-532.

6.3.2.1.2 Static Tests

a. Record the computer input and output analog voltages.

b. Tabulate the recorded computer input and output analog voltages as shown in Table I.

TABLE I. Static Test Data

AZ Dial	Synchro Output	Potentiometer Output
100.05 mils	100.3 mils	100.2 mv

6.3.2.1.3 Dynamic Tests

a. Record the computer input and output analog voltages.

b. Tabulate the recorded computer input and output analog voltages as shown in Table II.

Table II. Dynamic Open-Loop Test Data

Input	Constant Gain Amplifier (G)	Differentiator	Integrator
Constant d-c voltage (A)	Constant d-c voltage (G x A)	0	Saw tooth B (t)
A sin (W t)	G x A sin (w t)	B cos (w t)	C cos (w t)
Ramp A (t)	G x A (t)	B	C t^2

6.3.2.1.4 Dynamic Evaluation

Record the input variables and the output parameters for each computer problem.

6.3.2.2 Digital Computers

6.3.2.2.1 Input Unit - Static Tests

a. Record the output of each register and each shaft position.
b. Tabulate the recorded data as shown in Table III.

Table III. Static Digital Readout Data

Dial Shaft Position	Coded Digital Readout	Angle Units Per Bit	Digital Readout Calculated in Dial Unit
0.0	00000000000000	0.1	0.0
10.0	00000001100110	0.1	10.2

6.3.2.2.2 Input Unit Dynamic Tests

a. Record the input dial readings.
b. Record the outputs of the input unit.

6.3.2.2.3 Memory Unit Test

a. Record the access time and memory cycle time of the memory unit.

6.3.2.2.4 Arithmetic and Programming Units Test

a. Record the condition of any module in the arithmetic and programming digital system.

6.3.2.2.5 Computer Outputs and Displays Test

a. Record speed of operation.
b. Record adequacy of readout information.
c. Record ability to interpret registers on demand.

6.3.2.2.6 Systems Dynamic Testing

a. Record malfunctions and discrepancies noted during conduct of test.

6.3.2.3 Degree of Automation

a. Record all observations made during conduct of evaluation

6.4 DATA REDUCTION AND PRESENTATION

6.4.1 Data Reduction

6.4.1.1 Analog Computers

6.4.1.1.1 Individual Circuits Tests

a. Computing Amplifier Drift Test - Determine the drift stability time by measuring the time interval between the application of the zero input and the point where the output deteriorates beyond specifications.

b. Computing Amplifier Dynamic Range Test - The output recording for this subtest shall be annotated to show maximum positive and negative input signal levels. These levels shall be compared to specifications.

c. Limiter Tests - The data reduction for this subtest shall be as described in MTP 5-2-532.

d. Timer Tests - The data reduction for this subtest shall be as described in MTP 5-2-532.

e. Integrator Tests - The data reduction for this subtest shall be as described in MTP 5-2-532.

f. Differentiator Tests - The data reduction for this subtest shall be as described in MTP 5-2-532.

g. Control and Magnetic Amplifier Tests - The data reduction for this subtest shall be as described in MTP 5-2-532.

h. Comparator Tests - The data reduction for this subtest shall be as described in MTP 5-2-532.

i. Mixer Tests - The data reduction for this subtest shall be as described in MTP 5-2-532.

j. Amplifier Tests - The data reduction for this subtest shall be as described in MTP 5-2-532.

6.4.1.1.2 Static Tests

The tabulated data derived from the static tests shall be analyzed to determine the presence of bias and the standard deviation of the readings calculated. The sum of the bias and random errors shall be no less than the system accuracy requirements.

6.4.1.1.3 Dynamic Tests

The input analog voltages to the computer shall be compared with the processed data to establish dynamic accuracies including time lags. Dynamic accuracies and time lags must not exceed the system specifications. The coordinate conversion of the radar mount polar coordinate data must be performed and compared with the computer input data.

6.4.1.1.4 Dynamic Evaluation

Construct a Bode plot of each servo system within the computer and compare the results with specifications. Determine the bandpass characteristics of the servo loop and compare with the system requirements. Determine the magnitude and direction of commands, time-of-flight, miss-distance, and proper sequencing of switching functions, and compare with system requirements and specifications.

6.4.1.2 Digital Computers

6.4.1.2.1 Input Unit - Static Tests

Determine the static accuracy and precision of the input encoders and compare with specifications.

6.4.1.2.2 Input Unit - Dynamic Tests

Determine the accuracy, precision, and data rate capabilities of the input digitizers. In Table III, the least significant bit on the encoder is 0.1. This should be of sufficient precision to meet the system requirements. The precision is 0.1 and the accuracy, referenced to the dial, is 0.2. Reduce and compare the dial and digital data. The data rate of the encoder outputs must be compatible with system requirements.

6.4.1.2.3 Memory Unit Test

The recorded access time and the memory cycle time of the memory unit under test shall be compared with specifications. If required, the adequacy of the storage can best be determined by performing a paper study of the unit, based on the system requirements.

6.4.1.2 Arithmetic and Programming Units Test

Evaluate the recorded data to determine the adequacy of the units in terms of the real time operations involved. The computer logic organization shall be studied on a system's flow diagram and evaluated in the light of system requirements and economy of computer time.

6.4.1.2.5 Computer Outputs and Displays Test

The speed of operation, adequacy of readout information, and the ability to interpret registers on demand shall be compared with system requirements and specifications.

6.4.1.2.6 Systems Dynamic Testing

The outputs of the computer shall be compared with the acceptable solutions to determine the adequacy of system performance. A lack of adequate test programs should be considered a major system deficiency since it is considered that a built-in test program is required to determine the readiness of the computer for routine operations.

6.4.1.3 Degree of Automation

The degree of automation built into the guidance computer shall be determined and included in the overall evaluation of the computer.

6.4.2 Presentation

Processing of raw subtest data shall consist of organizing the data into tabular form under the appropriate subtest title. All test data shall be properly marked for identification and correlation to the test item in accordance with paragraph 6.3 as a minimum.

A written report shall accompany all test data and shall consist of conclusions and recommendations drawn from test results. The test engineer's opinion, concerning the success or failure of the item(s) evaluated, should be included. In addition, equipment specifications that will serve as the model for a comparison of the actual test results should be included.

Equipment evaluation usually will be limited to comparing the actual test results to the equipment specifications and the requirements as imposed by the intended usage. The results may also be compared to data gathered from previous tests of similar components.

APPENDIX A

GROUND GUIDANCE COMPUTERS

1. GENERAL

The following discussion provides for a better understanding of the circuits to be evaluated by this Materiel Test Procedure and is intended to show the relationship of computer equipment to related missile components.

2. MISSILE SYSTEM COMPUTERS

In a command guidance system, such as the Nike Hercules, the entire missile flight, or a major portion, is controlled by a ground guidance computer. In a semiactive guidance system, such as the Hawk, the ground based computer is used to position the launcher and provide necessary prelaunch data. Similar ground based computing functions are used in some passive homing systems and inertial systems to set necessary prelaunch information into the missileborne guidance computer.

Early systems, such as the Corporal, Nike Hercules, and Hawk, employ analog equipment entirely. More complex systems, such as Nike Zeus and Mauler employ digital or combinations of digital and analog equipment. In general, most functions can be performed by either type of mechanization. Analog equipment usually is simple, but more limited in its problem handling capabilities than digital equipment. In recent years, high speed general purpose digital computers have come into more extensive use in the missile guidance field.

Ground guidance computers are used in missile systems to perform one or more of the following functions:

a. To evaluate input data, such as position and/or velocity of the threat, priorities, and false alarm signals.
b. To perform necessary prelaunch calculations, such as launcher orientation (lead angles), missile firing time, and preprogrammed flight paths to be set in the missileborne guidance computer.
c. To calculate inflight guidance commands during all or a portion of the flight.
d. To calculate required warhead burst commands.
e. To monitor system readiness and determine selection of optimum missile
f. To evaluate the engagement miss distance and subsequent action

3. ANALOG COMPUTER TESTING

The testing of analog computers requires the use of precision test equipment, such as potentiometers, digital voltmeters, phase meters, strip chart recorders, function generators, and system programming equipment. The specific test procedures for each major element of an analog computer are discussed in paragraphs a. through e.

a. Input Elements -- Generally, the basic input into a missile system ground guidance computer is the output of the radar in the form of the angle and range information. When an analog computer is used, the most common form of output is a synchro transformer, a resolver or a potentiometer, or a combination of these devices. Often there are direct reading dials on the output shafts.

The normal tests performed on the radar shaft outputs are those to determine static and dynamic accuracy and precision. It generally is desirable to use test equipment having a precision and reading resolution which is an order greater than the system requirements for precision and accuracy. This is not always possible when the high precision requirements of some missile systems equal or exceed the state of the art of analog readout devices. In such cases, tests are performed with equipment having a precision factor of two greater than the system requirements.

1) Static Tests -- Normally, static tests are performed on the equipment in the field. Specific angles over the range of operation of the system are set by the use of the dials on the radar. The outputs are read on the test equipment and the data tabulated.
2) Dynamic Tests -- Dynamic tests also are generally performed in the field since the entire radar must be positioned. In general, the radar is slewed at various rates and the dial readings on the mount are photographed, preferably with high speed flash photography that is synchronized to a master clock. The input analog voltages to the computer are recorded on a suitable recorder as a function of clock time. Generally, the precision of measurement calls for recording in a digital form by use of an analog to digital converter.
3) Accuracy Requirements -- The greatest requirement for accuracy is at the input of the computer. The full precision and accuracy of the tracking radars must be transmitted to the computer. In general, the accuracy requirements are greatest in a command guidance system, such as the Nike Hercules. It is important to test with a degree of precision commensurate with the system requirements for accuracy. Accuracy requirements in excess of one part in 50,000 are not uncommon.
4) Transformation from Radar Polar Coordinates to Rectangular Coordinates -- For some systems, the transformation from radar polar coordinates to rectangular coordinates is accomplished by the use of sine-cosine potentiometers physically geared to the mechanical mount of the radar. In systems of this type, the computer inputs are rectangular coordinates. The degree of precision and accuracy required can be in excess of 1 part in 50,000. Methods of testing rectangular data outputs are identical to those for testing the inputs.

5) Long Term Drift -- Long term drift may be caused by mount alignment drift. Static accuracy tests should be performed over a period of 24 hours to determine the adequacy of alignment procedures.

b. Storage Units -- Generally, analog computations are performed on a real time basis and storage units are not used to store input data. Such parameters as preprogrammed trajectories may be stored as functions in a function generator. These should be tested for accuracy by recording the output as a function of time and comparing the output to the design equation.

c. Computing and Processing -- The basic analog computing element is the operational amplifier. The characteristics of operational amplifiers are adequately discussed in analog amplifier tests. Of specific interest in this MTP are the tests of greatest importance in the missile guidance computer. The analog computing functions may be divided into open end functional computations and closed loop computations.

1) Open End Functional Computations -- The open end computations involve precision amplifiers, (differentiators, integrators, and multipliers). The precision analog amplifier is generally of the d-c type. Stability requirements are exacting. Most amplifiers will have zero-set devices to assure the required stability over a long period of time. The simplest test method involves injecting known precision inputs in the form of static values or known functions and monitoring the computation at various points in the computer. It is important to use equipment and monitoring points that will not "load" the computer elements under test. Devices such as high input impedance digital voltmeters are particularly suited for this type of test. Some of the inputs are time varying functions such as the sine and saw tooth (ramp). It is important to use frequencies for these functions which are within the limits of the operational amplifiers' frequency response. In general, the computing functions involved in missile guidance problems are relatively low frequency functions such as 0.1 to 10 cps. A typical specific function generator which can be used for these tests is the HP 202A. This function generator produces sine, square, and triangular waves with one percent stability from 0.008 cps to 100 cps. The function generator will produce higher frequencies up to 1200 cps with degraded accuracy.

Another item which must be tested is the dynamic range of the computer amplifier. If an analog computer is designed to handle voltages from +100V to -100V, the operational amplifiers should be tested over this entire range. D-c operational amplifiers are subject to short and long term drifts. Zero set switches or chopper stabilized amplifiers are generally provided to reduce drift. These should be tested for adequacy and noise. The noise should not exceed the minimum resolution capability of the system.

2) Closed Loop Computing Elements -- The closed loop computing elements of a computer are essentially servo mechanisms and should be tested folowing the typical tests for servo systems. For this aspect of the computer, the computing elements rely on the sensitivity of the null sensing circuits and the frequency response characteristics of the servo loops. In general, the gain of amplifiers is not critical. A typical servo in a missile system ground guidance computer would be the time-to-intercept servo. Testing of these servos is best accomplished by injecting simulated missile flight and target trajectory data into the system. Of prime importance is the ability of the servo loops to handle the full threat spectrum for which the missile system was designed, such as the full range of expected target and missile velocities.

Many ground guidance computers will have servo bandwidth limiting features which are designed to minimize internal or target data noise. Generally, these elements are variable filters which are switched in and out at different parts of the engagement.

d. Output Elements -- The outputs of ground guidance computers generally are commands and displays or other forms of data presentation to aid human operators in making decisions relative to the engagement or to evaluate the effectiveness of the engagement.

1) Commands -- The output commands of the computer are easily monitored. They represent an element in the closed loop generally described as the missile-to-target loop. As for all servo systems, the magnitude of an element in the loop is not necessarily critical. Approximate magnitudes are generally satisfactory. But the direction or sense of the commands as well as frequency or data rate is essential to the successful completion of the engagement. In general, the direct output of an analog computer will be an analog voltage which is limited in its frequency content by the frequency response characteristics of the various servo loops in the computer. The requirement for frequency response is dictated by the ability of the missile to respond to commands. Command outputs are usually limited by the information rate of the communications link between the ground and the missile which is normally the pulse repetition frequency (PRF) of the missile radar. Since this rate generally is higher than the frequency response of the computer servo loops and the missile response capabilities, the commands are transmitted in sequence on a time sharing basis. For tests of the computer, it is usually more desirable

to plot the outputs of each channel on a strip chart recorder prior to the multiplexing and modulation of the commands in the missile radar. Many systems will routinely monitor these commands on a systems event recorder that is used to read the outputs of the computer under test conditions. Some tactical systems, essentially sealed units, do not have suitable monitor points provided on the computer output and due to their compact size can most easily be monitored by receiving and demodulating the transmitted commands. It is extremely difficult to inject a suitable problem into the computer to evaluate the commands when one remembers that this is part of a closed loop system. Simulated engagements offer the best method of analysis of the command loop.

2) Display and Monitor Devices -- Various outputs of the computer may be displayed or recorded to facilitate operation of the system, aid in making decisions, and evaluating the success of an engagement. Plotting boards, event recorders, and meters or dials are the most common monitor devices. Plotting boards are used to show the position of the target and missile. Often the predicted intercept point will be displayed. Event recorders show the progress of an engagement including such computer calculations as target and missile velocities, missile commands, and miss distance between target and missile intercept. Meters or dials may display the outputs of some computer calculations, such as time-to-intercept and miss distance. In general, monitoring of the computer outputs is useful during a test. However, the accuracy, frequency response, and stability of these output devices usually are not critical and hence do not justify testing in detail.

e. Dynamic Testing -- One of the more useful test techniques for evaluating a missile guidance system is dynamic testing. To evaluate the computer, a series of typical problems are fed into the computer on a real time basis. Since the computer operates as an element in a closed loop servo, it is necessary to close the loop in the dynamic test setup. This is best accomplished by simulating the missile transfer functions on a general purpose analog computer or by designing a special missile simulator to receive the computer commands and execute realistic missile movements in response to these commands. It is impossible to generalize the equipment to be of optimum utility for all systems under test without having a large general purpose analog computer. For proof-test work when many production units are to be checked out, a special purpose dynamic tester can be constructed for that system. The important criteria to be considered in the selection or design of a dynamic tester are discussed in subparagraphs 1 through 4 above.

1) Target Position Generator -- The output of the generator must be compatible with the input circuits in both form and impedance. Thus, if the computer receives synchro transmitter, or if the computer inputs are d-c voltages then the target position generators output should be in this form. The dynamic range of the target position generators must be compatible with the design targets of the system. The accuracy of the generators must be commensurate with the system accuracy requirements. Target generators that may be used include a function generator (similar to HP 202A), programmed computer (similar to Reeves), special mechanical dynamic programmers (similar to T-12), or internal slewing devices of the radar by use of aided rate functions.

2) Missile Simulator -- The primary purpose of the missile simulator is to reproduce the approximate missile flight by programming the simulated missile to respond to commands in pitch and yaw. To test the computer, it is not necessary to sophisticate this simulated missile with the full range of aerodynamic parameters that would be required for a full systems simulation study. A standard missile velocity as a function of time of flight can be used and set up in a function generator. For example, a cam cut to the velocity curve and rotated as a function of time of flight may be used. The missile velocity curve can be taken from actual flight data. If the missile trajectory is greatly different for various intercept altitudes and/or ranges, it may be necessary to select several different velocity functions to get reasonably good results.

The missile transfer functions can be simplified, but should be realistic. Realistic response times should be set.

Coordinate conversion from missile axes to radar polar on Cartesian coordinates can sometimes be simplified by limiting the engagements to be investigated to a particular course, such as an incoming course along one of the system coordinate axes. This limitation is not desirable, but it does enable a simplification of the missile simulator. This may be justified if the number of units to be prooftested is small.

The philosophy of the missile simulator cannot be over emphasized. The simulator need not be designed to explore aerodynamic and missile parameters. It must be designed with typical missile response characteristics to permit a realistic closed loop operation of the ground guidance computer.

3) Test and Evaluation Recorder -- The choice of a recorder to display the computer outputs is dictated by the number of channels required, the frequency response, and the accuracy and stability required. Generally, a strip chart recorder of the immediate read type (similar to the Sanborn or Visicorder)

is best suited for the purpose. These recorders are available with multiple channels of recording. The frequency response of the Sanborn is approximately 100 cps. This is adequate for all studies except in the case when the transient response is extremely rapid as during end game. The Visicorder can be equipped with higher frequency response galvanometers and hence, is more suitable for the high frequency problems.

4) Use of the Dynamic Tester -- The dynamic tester can be programmed to inject a typical target course or trajectory into the computer. On command, a simulated missile can be launched to intercept the target. The missile flight will be directed by the computer command outputs. One particularly useful test program consists of increasing the threat velocities and/or maneuvers and monitoring any outputs for indications of computer limiting. Another test consists of programming the same target course approximately ten times and evaluating the statistical variations in the computer outputs. This can be used to establish the presence of bias and the magnitude of random variations in computer output.

4. DIGITAL COMPUTER TESTING

Tests of digital computers generally are performed by running test routines through the computer. Tests of individual components generally are performed in the maintenance and repair procedures and not in prooftest. However, there may, at times, be a need in the prooftest program to ascertain the adequacy of the digital computer. Testing of digital computers may be divided into the elements of the computer, namely, input units, memory units, arithmetic and programming units, and output units including displays.

a. Parameters -- The basic parameters of the digital computer that must be considered are:

1) Logic Organization -- Prior to any testing of a digital computer, the logic organization of the computer must be clearly understood. Outside of the requirement for all the basic units, there is no single accepted organization of the digital computers in use in guided missile systems. A basic categorization may be made in terms of whether or not the computer is organized as an assembly of special purpose units, much as in the case of the analog computer performing simultaneous operations, or into a general purpose computer which is synchronized with a large high speed arithmetic unit to sequentially perform the necessary subroutines. Although this general categorization is based on the manner in which the majority of the computer operations are performed, there are often combinations of the two general concepts to handle special problems, such as, a special purpose computer for threat evaluation or an aspect of threat evaluation (decoy discrimination). This concept is often used in nonmilitary computers where

off-line operations are performed to handle special conversions prior to entry into the large central computer.

2) Word Length -- Another basic parameter of the computer which must be clearly understood prior to testing is the word length. Most computers have a fixed word length although some will employ more than one word length to handle special problems in the most economical manner in terms of time required for entry and execution of subroutines. The word is made up of bits, for example, 24 or 48 bits per word. A word can contain information on one or more parameters. The code used in a computer may be one of several standard codes, such as binary, octal, binary coded decimal, and straight decimal.

3) Clock Frequency -- Another important computer parameter that must be ascertained prior to testing is the clock frequency. This fixes the rate at which bits are generated and handled in the computer. The clock rate may be as high as 2 to 5 megacycles. Although if extreme high speed is not required, lower clock frequencies of the order of 100 to 500 kilocycles may be used. The clock frequency must be known so that suitable test equipment may be selected. For example, oscilloscopes, counters, and digital pulse generators must have a sufficiently high frequency response to permit their use in the computer under test. The trend in modern computers is to use higher clock frequencies than even the 2 to 5 mc when possible.

4) Test Equipment -- General purpose test equipment for engineering evaluation of digital computers consists of test word generators (digital pulse generators similar to the Texas Instrument 6200 and 6500 series), and word display units such as indicator banks, digital counters, digital printers, and oscilloscopes. One of the more useful instruments for digital computer testing is the dual-beam or dual-gun oscilloscope (similar to the Tektronix Model 551 or 555). This type oscilloscope permits simultaneous observation of a test word at two test poi ts. Oscilloscopes with memory devices (similar to the Hughes Memo-Scope) are also helpful.

b. Input Units -- The principal test to be performed on the input units is to determine the accuracy, precision, and data rate capabilities of the input digitizers. Since most input data are the output of the radar, it is important to determine that the precision, accuracy, stability, and data rate of these devices meet the requirements of the system. Most digital systems will have a display device, such as lights, to indicate the state of output registers. The encoding devices (digitizers) will have either parallel or serial outputs. If the outputs are serial, some form of memory registers will be associated with these outputs. The position of the radar shaft angles can be determined from precision dials on the mount. The mount can successively be set to positions over the entire range of operation. This will provide for a test of the static accuracy and precision of the input encoder.

Dynamic tests may be conducted by recording the dial position with a dial camera and the digital readout on magnetic tape (similar to a Potter Digital tape). Both dial and digital data are recorded as a function of time. After the data are reduced, the listings are compared. The data rate of the encoder outputs must be compatible with system requirements.

c. Memory Units -- There are many memory units associated with the digital computers used in guided missile systems. In general, they are of two types, permanent or fixed memory units and working memory units. The permanent or fixed units store systems operating data such as preprogrammed missile trajectories, threat parameters, decision functions, and computer programs. The working memory stores parameters which are generated in the course of an engagement and are used for some later operation, such as the position of the target, the result of an intermediate computation, predicted positions of target and missile, and state of readiness of missiles. A working memory must be erasable. Permanent memories may or may not be erasable. If a permanent memory is erasable, it is generally read and re-entered as part of the same operation.

Tests on memory units generally are of the form of determining their adequacy in capacity and read and write times. For a military computer, the ruggedness of the memory unit must be considered as some memory units are fragile. Tests on memory units can best be accomplished by reading the input and output on a dual-beam or dual-gun oscilloscope (similar to Tektronix Model 555).

d. Arithmetic and Programming Units -- A digital computer performs arithmetic operations, such as addition and subtraction and calculates decisions based on a logic that is set into the program. With the high speeds available in present digital computers, a large amount of computing may be accomplished during the interpulse period of the basic radar pulse repetition frequency. There is no unique programming or logic that is ideally suited to the guided missile problem. Tests may be performed to ascertain the time required for various operations, such as bit and/or work transfer time, memory cycle time, and entry and readout times. In a prooftest evaluation there is little practical value to be gained in determining these parameters. If it is necessary to determine the condition of any module in the digital system, the use of a test word and dual-beam oscilloscope is recommended.

e. Computer Outputs and Displays -- The outputs of the digital computer normally will be digital numbers that are recorded on magnetic tape and/or displayed on a light bank indicator. At times the output of the computer will be converted into an analog voltage and used to perform an analog function, such as modulation of a transmitter. Tests of the output devices include tests for speed of operation, adequacy of readout information, such as the number of digits displayed, and the ability to interpret registers on demand.

f. Systems Dynamic Testing -- Most digital computers will have included, as part of the systems checkout, a routine program to exercise the computer and indicate units which are not operational. Such programs generally are digital tapes or cards that present realistic engagements to the computer. The outputs are compared either automatically or manually with the acceptable solutions to determine the adequacy of system performance. If a tape is not provided in the system to perform this type of test, a tape should be prepared as part of the engineering evaluation program.

If it is desirable to test the capability of the system against the extremes of system operation, such as target speed or threat saturation, a special tape with the required problem may need to be prepared. In general, however, it is anticipated that the majority of digital computers can be given an adequate prooftest by using the test programs built into the system.

5. DEGREE OF AUTOMATION

The degree of automation built into each missile guidance computer will vary to meet the needs of the system. At the present, the selective use of the human operator can considerably simplify the computer. In an engineering evaluation program, the items that must be evaluated on the use of the human operator are:

a. Availability of sufficient data for the operator to make decisions or perform a part of the computer operation.
b. Adequacy of the displays in terms of accessibility, readability, and information rate.

The functions of the human operation are best evaluated by programming the system through dynamic tests on an actual evaluation of the operator functions during a test engagement.

GLOSSARY

1. Aerodynamic Parameters: Reactions caused by the relative motion between air and a solid which are constant under a set of circumstances being considered at the moment, but which may have different values under other aerodynamic circumstances.

2. Analog Computer: A computing device which performs computing operations with a continuous acting mechanism.

3. Analog to Digital Converter (A to D): A device which changes an analog quantity into a digital quantity, such as voltage to a decimal or binary quantity.

4. Bias Error: A relatively constant error in one direction over a relatively extended period of time.

5. Binary: A digital format based on a two state information signal with total value expressed as terms in powers of two.

6. Binary Coded Decimal: A digital format consisting of a binary grouping of four bits for each decimal value.

7. Bit: A discrete minimal unit used in a digital computer. One unit of a binary number.

8. Bode Plot: A plot of transfer function of a device. The relationship of the output to the input. The output signal amplitude is plotted in decibels relative to the input signal amplitude as a function of input signal frequency.

9. Clock Pulse: A signal from the master clock used to identify bit times and time synchronized computer operations.

10. Command Loop: The elements of the system which are required to generate, execute, and sense the commands which are sent to the missile in accordance with the guidance plan.

11. Digital Computer: A computing device which performs computing operations with discrete numerical quantities, usually by the iteration of addition and subtraction in counting devices.

12. Digital to Analog Converter (D to A): A device which changes a digital quantity into an analog quantity, such as a digital number to an analog voltage.

13. Digitizer: A device used to change an analog input, such as a shaft position into a digital output of discrete bits.

14. Logic Organization: The organization and interrelation of the computing functions to achieve the desired mathematical computations and decisions.

15. Octal: A digital format consisting of a binary grouping of three information bits to indicate each term of eight.

16. Operational Amplifier: A basic amplifier used in an analog computer to execute the required computer operations.

17. Polar Coordinate: Either of two numbers that locate a point in a plane by its distance from a fixed point on a line and the angle this makes from a fixed line. Polar coordinates are a direction (angle) and a distance (radius) from the origin.

18. Program: The plan for the computational sequences to be performed to execute the solution to a given problem.

19. Quantitizer: (Same as digitizer, term 13).

20. Rectangular Coordinates: A system defined in terms of three fixed axes which are mutually perpendicular at a common point, usually denoted by x, y, and z.

21. Resolver: An analog device to convert shaft position into an a-c phase function.

22. Sine-Cosine Potentiometer: A device especially designed to transform polar coordinates into rectangular coordinates.

23. Standard Deviation: The root-mean-square value of the deviation of a series.

24. Storage Unit: A device used to store digital information in a computer for a fixed or indefinite period of time. Sometimes called a memory device.

25. Synchro: An analog device to convert shaft position into an a-c voltage and/or phase function.

26. Transfer Functions: A relationship between one system variable and another that enables the second variable to be determined from the first.

27. Transient Response: The response of a system to a suddenly impressed force of pressure.

28. Threat Parameter: The characteristics of the threat which determine the defensive system requirements, such as target size, number of targets, speed, and altitude.

29. Word: An ordered set of characters or bits which may be stored, transmitted, or operated upon within a digital computer.